Low Energy Program Overview

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Introduction

The low-energy nuclear physics program focuses on the study of nuclear properties under extreme conditions and uses nuclei as a quantum system to test fundamental symmetries and to understand the weak interaction. Most of the studies use beams provided by the 88-Inch Cyclotron to produce nuclei with high angular momentum, high temperature, an excess numbers of neutrons or protons as well as new super-heavy elements. State-of-the-art instrumentation developed at LBNL was used for these experiments. The Berkeley Gas-Filled Separator (BGS), which was completed in 1998, provided the capability to discover the new super-heavy elements 118 and 116; a major breakthrough in the quest for an island of super-heavy nuclei. The new radioactive beam capability (BEARS) provided a beam of ^{11}C which was used in several experiments with world record intensity and energy for this beam. Additional exotic beams such as ^{14}O are being developed. Other unique facilities that have lead to important discoveries and new physics insights are a magneto-optical atom trap, the 8-π gamma-ray array, and various particle detector systems. In addition, the development of a next generation gamma-ray array(GRETA) and an ^{14}O source for precision beta-decay measurement have made significant progress in this year.

The 88-Inch cyclotron is a national facility, and experimental proposals are reviewed by a program advisory committee. The cyclotron provides beams of most elements using two state-of-the-art ECR ion sources. Beams from helium to neon are available with energies up to 30 MeV/nucleon and for heavier beams the maximum energy decreases with increased mass, reaching 5 MeV/nucleon for lead. The high intensity and high reliability combined with the ease of changing beam type and energy makes the 88-Inch Cyclotron the ideal accelerator for both nuclear structure and reaction studies. In FY99, the cyclotron provided beams for 118 experiments and a total of 4519 hours of beam on target.

The Berkeley Gas-Filled Separator

Construction of the Berkeley Gas-Filled Separator (BGS), by the heavy element group, was completed in 1998. Following several commissioning runs, an experiment was carried out to search for the new element 118 using the $^{86}Kr + ^{208}Pb$ reaction. Three decay chains were observed, each consists of an implanted compound nucleus followed by a cascade of high energy alpha particles. The energies and lifetimes of the alpha decays are consistent with the decay of element 118 with mass number 293 (produced in the one-neutron emission channel) and of its daughters. The production cross section of about 2 pb is much larger than expected from systematics based on the production of elements 102 to 112. The increased cross section may be due to the "unshielded fusion" mechanism and signals a potential to synthesis a large number of new elements and isotopes. The BGS focal plane detector and the data acquisition systems are being upgraded. The new system will be used first for the measurement of the excitation function of the $^{86}Kr + ^{208}Pb$ reaction. The results will be used to determine the optimal beam energy for the production of element 119 using either the $^{86}Kr + ^{209}Bi$ or the $^{87}Rb + ^{208}Pb$ reaction. BGS is operated as a national user facility. In addition to the search for super-heavy elements, experiments have been carried out successfully in the search for long-lived isotopes of element 107 (Bh), and the first chemical study was carried out using the new isotope ^{267}Bh.

BEARS

BEARS, Berkeley Experiments with Accelerated Radioactive Species, began full operation this year and produced its first beam of ^{11}C. The radioactive nuclei are produced at the medical cyclotron in building 56 and are transferred in gaseous form to building 88 through a 350-meter transfer line. The cryogenic trapping of the activity, the separation of the carrier gas, and the injection into the AECR source are controlled automatically. A continuous ^{11}C beam with an intensity up to 2 x 10^8 ions/s at an energy up to 125 MeV was produced for several experiments and represent the highest intensity and energy achieved for a ^{11}C beam. Development of a ^{14}O beam has begun and a beam intensity of 1 x 10^6 ions/s is projected. Other beams, such as ^{13}N, ^{15}O, $^{17,18}F$, and ^{19}Ne, are planned.

Nuclear Structure

The 8-π gamma-ray array from Chalk River was installed in Cave 4C and operation began in April 98. This array, with its multiplicity/total energy inner ball and a CsI detector array for light charged particles, is operated as a user facility. During this year 23 experiments have been carried out for a total beam time of 1463 hours. In addition to LBNL staff, users included groups from three US National Laboratories, eight US Universities and six foreign institutions. This array is being disassembled and will be shipped to TRIUMF before April 2000 to make cave 4c available for the return of Gammasphere.

GRETA (Gamma-Ray energy Tracking Array) is a new concept in Ge detector arrays and has the potential of providing 100 to 1000 times the sensitivity of Gammasphere. This year the research and development effort has achieved several important milestones. The essential component of the array, a second prototype detector with 36-fold segmentation, has been received. Fast preamplifiers designed for pulse shape analysis were manufactured and installed at LBNL. A number of test measurements have been performed including noise, response function, as well as energy, time and position resolutions. A position sensitivity in three dimensions of 0.2 - 0.5 mm was measured. This is much better than the requirement for gamma-ray energy tracking algorithms. Several algorithms have been developed for decomposing signals of multiple interactions events. These studies indicate that an algorithm with sufficient accuracy and speed could be developed for online data processing. Other areas of R&D carried out this year included algorithms for timing determination, anisotropy of electron and hole velocities in Ge detectors, and tracking of pair-production events.

The nuclear structure group studies the complex many-body properties of nuclei (sometimes referred to as emergent properties) in terms of the elementary modes of excitation: rotation, vibration, single-particle, pairing, etc. By subjecting the nucleus to extreme conditions, encountered, for example, at high angular momenta and diverse proton to neutron ratios, the subsequent gamma-ray decays (observed in multi-Ge detector arrays, e.g. Gammasphere, 8π) can be used to isolate and study the various phenomena that emerge. The group's research has focused on two areas; nuclei at high spins and nuclei with N ~ Z. The outstanding question for N=Z nuclei has been whether they can sustain a new form of pairing condensate comprising np pairs (deuteron-like) coupled to isospin T=0. Normal paring contains T=1 pairs. From an analysis of binding energies of N=Z nuclei we have clearly shown that there is no evidence to support the existence of a T=0 pairing phase in the ground state, contrary to some calculations. Experiments to further investigate the properties of N ~ Z nuclei were carried out on ^{98}Cd (where we confirmed that the polarization charges are not anomalous, as previously reported), and ^{36}Ar (where, at high spins, superdeformation was discovered - marking a new region of superdeformation that will provide a crucial test for large scale shell model calculations that promise a fully microscopic description of very deformed rotational nuclei). Notable highlights from the high-spin studies include; (i) study of high-spin structure of exotic, neutron-rich isotopes via ^{208}Pb + ^{238}U deep-inelastic collisions, and (ii) Discovery of signature dependent prolate-oblate interaction strength in ^{185}Hg.

Weak Interactions

The weak interaction group takes advantage of the unique capability of the 88-Inch cyclotron to provide high-intensity light-ion beams used to produce exotic nuclei for precision studies of weak interaction parameters in the search for physics beyond the standard model. A new detector system completed this year was used to measure the electron-neutrino angular correlation in the beta decay of laser-trapped ^{21}Na atoms. This measurement will set a limit on possible scalar and tensor contributions to the electroweak currents. A preliminary analysis of the data yield a 15% statistical uncertainty in the correction and additional measurements are planned. For an experiment to test the Conserved Vector Current hypothesis, a new ECR source was installed to ionize radioactive ^{14}O produced by a ^{3}He beam from 88-Inch Cylotron on a ^{12}C target. Improvements in the target and transfer line make 1 x 10^8 atoms per second availiable for injection into the ion source, and an ion beam of 1.5 x10^6 ions per second has been produced. The ions will be implanted in a thin foil for precision beta-spectrum measurements. As part of the emiT collaboration, this group has determined a better limit on the possible time reversal invariance violation in polarized neutron beta decay.

Reaction Mechanism

The study of multifragmentation, the breakup of excited nuclei, has been a rich source of new theoretical understanding in terms of simple stochastic relations. This year two statistical properties, reducibility (the many-particle emission probability reduces to a one-particle probability) and thermal scaling (the one-particle probability scales like a Boltzmann factor), have been demonstrated to be features of a model describing the condensation of droplets from a vapor near its critical point (Fisher's droplet model). This observation has prompted a new analysis which has yielded a deeper insight into the mechanism behind multifragmentation. When applied to the EOS 1 AGeV Au+C multifragmentation data set, this analysis yielded results consistent with a small system undergoing a continuous phase transition, gave an estimate of the surface to volume critical exponent (2/3) and a measure of the surface energy coefficient for a low density nuclear system (6.4 MeV). The development of analyses which can reveal signals of a phase transition in small systems has become an increasingly important topic in the nuclear physics community.